

# Energy Potential Study of Some Tropical Wood Species from Nigeria

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## ABSTRACT

**Aims:** To carry out experimental study of the energy potential of some tropical wood species.

**Study design:** It involved sample collection, experimental analysis and numerical validation of the obtained calorific values.

**Place and Duration of Study:** National Centre for Energy Research and Development (NCERD), University of Nigeria, Nsukka, Enugu State, Nigeria between November 2016 and September 2018.

**Methodology:** Wood waste (saw dust) from ten (10) selected tropical wood species sourced from sawmills in Benin City, Nigeria were subjected to proximate analysis, ultimate analysis as well as energy content study.

**Results:** Thermal conversion characteristics of low ash content (0.2 – 2.76 %), very high volatile matter (87.51 – 90.94%), low moisture content (8.62 – 10.53%), relatively high carbon, hydrogen and oxygen contents as well as low nitrogen and sulphur contents were observed. Obtained calorific values were validated using three already existing correlations.

**Conclusion:** Among the 10 species studied, *Azelia africana* (Apa) was found to be best suited for energy generation while *Triplocyton scleroxylon* (Obeche) was found to be least suited.

**Keywords:** Energy; wood waste; ultimate analysis; proximate analysis; calorific value.

## 1. INTRODUCTION

One of the key factors that drive the development of a country is the availability of electricity [1-2]. With Nigeria currently experiencing inadequate supply of electricity, there is a great need for the application of renewable sources of energy to complement the current fossil fuel-based power systems which account for about 65% of the electricity produced in the country [3]. Though renewable sources such as the hydro and solar are already being applied, there's need to increase the energy mix to include other renewable sources which are readily available. One of such sources is biomass, specifically wood or wood residues.

Wood wastes (sawdust, off-cuts, wood barks, plain shavings as well as rejects) are available in Nigeria in large amounts [4]. The trees which are obtained from forest reserves approved and developed by the government for logging purpose find use in various end value applications such as furniture works, paper production and as a source of fuel for cooking.

The quantity of this energy resource that is generated in Nigeria is estimated to be in the range of 1.8 to 5.2 million tonnes per annum [5-8]. These wood wastes which greatly contribute to the pollution of the ecosystem owing to their current disposal methods [9-10] would readily aid in attaining adequate power supply if optimally applied. One of the major reasons for the poor exploitation of this great resource lies in the lack of adequate data with

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35 regards to the energy potential of the available local wood species unlike the coniferous  
36 wood species such as the spruce and willows which are specially grown and developed for  
37 the sole purpose of energy generation in most parts of Europe due to their energy content  
38 and thermophysical properties. A knowledge of the energy potential of local wood species is  
39 therefore very important in planning effective ways of exploiting and utilizing our forest  
40 resources (wood) for energy production, hence the need for this work.

41 A number of efforts have been made in the study of wood waste as a potential national  
42 source of energy. Aina et al. [11] reported the energy potential of wood wastes with regards  
43 to charcoal production for domestic use as an alternative cooking fuel. Akintunde and Seriki  
44 [12] investigated the effect of mixing paper waste with sawdust briquette as a means of  
45 improving its calorific value (CV). Akinola and Fapetu [13] evaluated energy availability in  
46 seven (7) tropical wood species obtained from Akure, Nigeria which include; Obeche  
47 (*Triplochiton scleroxylon*); Iroko (*Melicia excelsa*); Danta (*Nesogordonia papaverifera*);  
48 Mahogany (*Khaya ivorensis*); Omo (*Cordia platythyrsa*); Mansonia (*Mansonia altissima*) and  
49 Afara (*Terminalia superba*). They reported an average energy content of 21.754 MJ/kg and  
50 electricity equivalent of 6.06kWh per kg of wood biomass pyrolyzed. More recently, Akhator  
51 et al. [14] experimentally investigated the physico-chemical properties and energy potential  
52 of wood wastes from five (5) tropical species obtained from sawmills in Benin Metropolis  
53 which include Ekki (*Lophira alata*), Ohia (*Celtis sp*), Danta (*Nesogordonia papaverifera*),  
54 Omah (*Cordia millenii*), Black Afara (*Terminalia superba*). They reported suitability of the  
55 woods as feedstock for renewable energy generation on account of their high thermal  
56 energy potential values. Considering the numerous wood species that abound in the tropics,  
57 this study is therefore aimed at investigating the energy potential of other wood species in  
58 Nigeria not previously studied with a view to boosting the data base for biomass application  
59 and energy policy formulation.

## 62 2. MATERIAL AND METHODS

63  
64 In this experimental study, wood waste from ten (10) tropical wood species of class size 45-  
65 60cm diameter and mean age of 110 years were analysed to determine their potential for  
66 energy conversion application. They include *Acacia sp* (Acacia), *Azelia africana* (Apa),  
67 *Celtis sp* (Ohian), *Brachystegia eurycoma* (Okwen), *Bombax bounopozense* (Bombax),  
68 *Blighia sapida* (Ukpe), *Piptadeniastrum africanum* (Ekhimi), *Cleistopholis partens* (Otu),  
69 *Triplocyton scleroxylon* (Obeche) and *Albizia sp* (Albizia) [15]. These wood waste samples  
70 were obtained from 14 sawmills located within Benin City, Edo State, Nigeria. These wood  
71 species which are predominantly heartwoods on account of their ages and structure are also  
72 grown in Ogun, Ekiti and Ondo States of Nigeria. The obtained waste samples were dried to  
73 reduce the moisture content and equal mass for each specie was then subjected to  
74 experimental procedures as briefly discussed in the following sections.

75 Some of the materials used in this study include: bomb calorimeter, moisture analyser, oven,  
76 muffle furnace, fume cupboard, micro-Kjedahl digestion flask (500ml capacity), Ohaus  
77 weighing balance, micro-Kjedahl distillation unit, 100 ml conical flask and reagents.  
78 Proximate analysis and ultimate analysis were carried out while the calorific values of the  
79 selected species were also determined.

### 81 2.1 Proximate Analysis

82 The proximate analysis indicates the behaviour of the wood waste when it is heated. It  
83 consists of the Moisture Content (%MC), Ash Content (%A), Volatile Matter (%VM) as well  
84 the Fixed Carbon (%FC) [16].

#### 86 2.1.1 Moisture Content (MC)

87 The moisture content which is an indicator of the amount of water in a wood sample was  
88 determined using the Association of Analytical Chemists method (AOAC) [17]. Porcelain  
89 crucibles were washed and dried in an oven at 100°C for 30 minutes and allowed to cool in a  
90 desiccator. 1 gram of the sample was placed into weighed crucibles and then put inside the  
91 oven set at 105°C for 4 hours. The samples were removed from the oven after this period  
92 and then cooled and weighed. This process was repeated for all the samples with the  
93 crucibles weighed until a constant weight was obtained. The formula used for determining  
94 the percentage moisture content [17] is given as:

$$95 \quad \% \text{ MC} = \frac{(g-x)}{g} \times 100$$

96 (1)

97 Where, g is the mass of sample, x is the mass of dry matter and (g - x) represents the loss in  
98 mass.

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### 100 **2.1.2 Ash Content (A)**

101 The AOAC experimental procedure [17] was applied. The residue remaining after all the  
102 moisture have been removed and the fats, proteins, carbohydrates, vitamins and organic  
103 acids burnt away by ignition at about 600°C is called ash. It is usually taken as a measure of  
104 the mineral content of the raw waste. Using AOAC method [17], 1gram of the finely ground  
105 samples was weighed into porcelain crucibles which have been washed, dried in an oven at  
106 100°C, cooled in a desiccator and weighed. They were then placed inside a muffle furnace  
107 and heated at 600°C for 4 hours. After this, they were removed and cooled in a desiccator  
108 and then weighed. The percentage ash content was obtained thus:

$$109 \quad \% \text{ Ash} = \left(\frac{y}{g}\right) \times 100 \quad (2)$$

110 Where, g is the mass of sample and y is the mass of ash.

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### 112 **2.1.3 Volatile Matter (VM)**

113 The method described by Meynell [18] was used. The dried residue was heated in a muffle  
114 furnace at 600°C for two hours. The heated residue was cooled in a dessicator and weighed.

$$115 \quad \% \text{ VM} = \left(\frac{w-z}{g}\right) \times 100 \quad (3)$$

116 Where, g is the mass of sample, w is the mass of dry matter and z is the mass of residue.

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### 118 **2.1.4 Fixed Carbon**

119 This was done according to Berkowitz method [19] as shown below:

$$120 \quad \% \text{ FC} = 100 - (VM + Ash + MC) \quad (4)$$

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## 122 **2.2 Ultimate Analysis (Dry)**

123 The Ultimate Analysis gives the chemical elements (Carbon, Oxygen, Hydrogen, Nitrogen,  
124 Sulphur) that comprises the wood waste substances together with the ash content [16].

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### 126 **2.2.1 Carbon Content**

127 In this analysis, the method prescribed by Walkley and Black [20] was used.

$$128 \quad \% \text{ Carbon} = \frac{0.399 \times (B-T) \times m}{g} \quad (5)$$

129 Where, B is the blank titre, T is the sample titre, g is the mass of sample and m is the  
130 molarity of ferrous ammonium sulphate solution.

131

### 132 **2.2.2 Nitrogen Content**

133 The micro-Kjedahl method as described by Pearson [21] was used.

$$134 \quad \% \text{ Nitrogen} = \frac{(T \times M \times 0.014 \times DF)}{g} \times 100 \quad (6)$$

135 Where, M is the molarity of the acid used, g is the mass of sample, T is the Titre value and  
136 DF represents the Dillusion factor.

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### 138 **2.2.3 Sulphur Content**

139 1g of the pulverized wood sample was mixed with 3g of a mixture of magnesium oxide and  
140 anhydrous sodium carbonate (2:1). The mixture was heated to 400°C for two hours in a  
141 muffle furnace. It was cooled and digested in water, after which barium chloride was added  
142 to precipitate the sulphate as barium sulphate (BaSO<sub>4</sub>). The precipitate was then filtered and  
143 the amount of sulphur determined.

$$144 \quad \% \text{ Sulphur} = \frac{s \times b}{g} \times 100 \quad (7)$$

145 Where, s is the mass of BaSO<sub>4</sub>, b represents the atomic mass of barium (0.1373) and g is  
146 the mass of sample.

147

### 148 **2.2.4 Hydrogen Content**

$$149 \quad \% \text{ Hydrogen} = \text{Mass of H}_2\text{O} \times \frac{0.1119 \times 100}{\text{mass of pellet}} \quad (8)$$

150 Where 0.1119 is a constant derived from empirical equation in Leibig-Pregle method.

151

### 152 **2.2.5 Oxygen content**

153 The oxygen content was obtained using equation (9).

$$154 \quad \% \text{ Oxygen} = 100 - (C + H + N + S + \text{Ash}) \quad (9)$$

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## 157 **2.3 Calorific Value, Energy Content and Electrical Power**

158 Calorific value (CV) is defined as the amount of energy per unit mass or volume released on  
159 complete combustion of a fuel. The calorific value is the maximum usable heating value  
160 released in complete burning of a specific volume of fuel. In this analysis, AOAC procedure  
161 [22] was applied using the bomb calorimeter. 1g of the sample pellets was burned in the  
162 oxygen model bomb calorimeter. The heat of combustion was calculated as the gross  
163 energy.

164 The formula used for determining the calorific value as stated in AOAC [22] is given as:

$$165 \quad \text{Calorific value} = \frac{E \Delta T - \phi - V}{g} \times 100 \quad (10)$$

166 Where, E is the energy equivalent of the calorimeter = 13,039.308 kJ/kg,  $\Phi = 2.3 \times$  burnt  
167 wire, V is the volume of calorimeter,  $\Delta T$  is the change in temperature and g is the sample  
168 mass.

169 In order to validate the obtained experimental CV, three correlations: Channiwala and Parikh  
170 [23], Yin [24] and Garcias *et al.* [25] from literature developed for the prediction of the  
171 calorific values of various biomass were applied. The choice of these equations was mainly  
172 based on their applicability to wood wastes as they were developed variously as functions of  
173 the ultimate analysis [23-24] as well as a combination of ultimate and proximate analyses  
174 [25]. The applied equations are as follow;

$$175 \quad CV = 0.3491C + 1.1783H + 0.1005S - 0.1034O - 0.0151N - 0.0211A \quad [23] \quad (11)$$

$$176 \quad CV = 0.2949C + 0.8250H \quad [24] \quad (12)$$

$$177 \quad CV = 10.8 - 0.0984A + 0.1133FC - 0.1653M + 0.1277C + 0.0196O \quad [25] \quad (13)$$

178 Where, A, C, H, S, O, N, FC and M represents Ash, Carbon, Hydrogen, Sulphur, Oxygen,  
179 Nitrogen, Fixed Carbon and Moisture Contents of the material, respectively, expressed on  
180 the basis of percentage dry weight.

181 Having obtained the CV of each wood specie, the energy content or thermal energy potential  
182 (MJ) was then determined using equation (14) below as given by Olisa and Kotingo [26];

$$183 \quad EC = \rho \times v \times CV \quad (14)$$

184 Where,  $\rho$  is the wood sample density (kg/m<sup>3</sup>), v is the volume of wood processed (m<sup>3</sup>) and  
185 CV is the calorific value (MJ/kg).

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188 **3. RESULTS AND DISCUSSION**

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190 **3.1 Proximate Analysis**

191 Table 1 presents the proximate analysis of the selected wood species.

192

193 **Table 1. Proximate analysis of wood samples**

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S/N	Wood species	Fixed Carbon (%)	Volatile Matter (%)	Moisture Content (%)	Ash (%)
1.	<i>Acacia sp</i> (Acacia)	0.35	89.37	9.68	0.6
2.	<i>Azelia africana</i> (Apa)	0.46	88.23	10.00	1.31
3.	<i>Celtis sp</i> (Ohian)	0.12	88.92	9.84	1.12
4.	<i>Brachystegia eurycoma</i> (Okwen)	0.21	87.51	9.52	2.76
5.	<i>Bombax bounopozense</i> (Bombax)	0.08	87.69	10.17	2.06
6.	<i>Blighia sapida</i> (Ukpe)	0.34	88.71	9.84	1.11
7.	<i>Piptadeniastrum africanum</i> (Ekhimi)	0.18	89.38	10.17	0.27
8.	<i>Cleistopholis partens</i> (Otu)	0.05	88.16	10.53	1.26
9.	<i>Triplocyton scleroxylon</i> (Obeche)	0.17	90.21	9.09	0.53
10.	<i>Albizia sp</i> (Albizia)	0.24	90.94	8.62	0.2
<b>Mean</b>		<b>0.22</b>	<b>88.91</b>	<b>9.75</b>	<b>1.12</b>
<b>Standard Deviation</b>		<b>±0.129</b>	<b>±1.093</b>	<b>±0.559</b>	<b>±0.804</b>

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196 The fixed carbon content which is a major factor in the determination of the heating value  
 197 ranged from 0.05 – 0.46% with the lowest and highest values obtained for *Cleistopholis*  
 198 *partens* (Otu) and *Azelia africana* (Apa) respectively. With regards to the volatile matter  
 199 composition, a range of 87.51 – 90.94% was obtained with a mean of 88.91% and a  
 200 standard deviation of ±1.093. This result is in total agreement with the submission of Akinola  
 201 and Fapetu [13] as well as Huhtinen [27] who analysed woods from European forests such  
 202 as pines, spruce, birch and alder. These studies reported that the volatile matter composition  
 203 of wood is typically high and above 80%. The ash content was typically low ranging from 0.2  
 204 – 2.76 % and this was desirable on account of its enhancing effect on the heating value [28].  
 205 This low ash content and very high volatile matter are highly desirable qualities as they show  
 206 good suitability of the wood specie for thermal energy conversion application brought about  
 207 by the high hydrocarbon quantity they indicate [13,14]. The moisture content ranged from  
 208 8.62 – 10.53%. These low moisture content values are very desirable as it enhances the  
 209 thermochemical conversion process [27] and also increases the thermal energy to be  
 210 obtained from the process since less energy will be required to vaporize it [13].

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212 **3.2 Ultimate Analysis**

213 Table 2 presents the ultimate analysis of the selected wood species samples on the basis of  
 214 percentage dry weight

215

216 **Table 2. Ultimate analysis of wood samples**

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Wood specie	Carbon (%)	Hydrogen (%)	Oxygen (%)	Nitrogen (%)	Sulphur (%)
<i>Acacia sp</i> (Acacia)	59.05	5.46	35.13	0.32	0.03
<i>Azelia africana</i> (Apa)	58.26	5.27	36.15	0.29	0.03
<i>Celtis sp</i> (Ohian)	55.06	5.04	39.62	0.25	0.03
<i>Brachystegia eurycoma</i> (Okwen)	47.72	5.74	46.35	0.18	0.02
<i>Bombax bounopozense</i> (Bombax)	45.38	5.53	48.94	0.14	0.01
<i>Blighia sapida</i> (Ukpe)	56.66	5.16	37.88	0.28	0.03

<i>Piptadeniastrum africanum</i> (Ekhimi)	52.67	5.60	41.48	0.24	0.02
<i>Cleistopholis partens</i> (Otu)	49.11	5.33	45.34	0.20	0.02
<i>Triplocyton scleroxylon</i> (Obeche)	46.28	5.46	48.07	0.17	0.02
<i>Albizia sp</i> (Albizia)	50.07	5.53	44.16	0.22	0.02
<b>Mean</b>	<b>52.03</b>	<b>5.41</b>	<b>42.31</b>	<b>0.23</b>	<b>0.023</b>
<b>Standard Deviation</b>	<b>±5.03</b>	<b>±0.21</b>	<b>±4.98</b>	<b>±0.06</b>	<b>±0.007</b>

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The carbon composition was highest for eight (8) out of the ten (10) species with the exceptions being *Bombax bounopozense* (Bombax) and *Triplocyton scleroxylon* (Obeche) in which the oxygen composition was higher by about 2%. The carbon content ranged from 46.28 – 59.05%. This result of relatively high carbon content which is desirable on account of its influence in increasing the heating value is in close agreement with the results obtained by Akinola and Fapetu [13] who reported a range of 50 -60% and Akhator et al. [14], 55.35 - 58.92% using other tropical wood species. The relatively high hydrogen and oxygen contents typically indicate high energy potential since they in conjunction with the carbon form the active reactants in the combustion process. The nitrogen and sulphur contents are low as expected and desired since this will ensure very low emission of NOx and SOx as products of combustion. These results agree with the report of Hutiheh [27] on the expected chemical content of wood fuels.

### 3.3 Density, Calorific Value and Energy Content

Table 3 presents the densities of the species as obtained from Carsan *et al.* [29], the experimentally obtained calorific values as well as the calculated energy contents.

**Table 3. Density, Calorific Value, Energy Content of wood samples.**

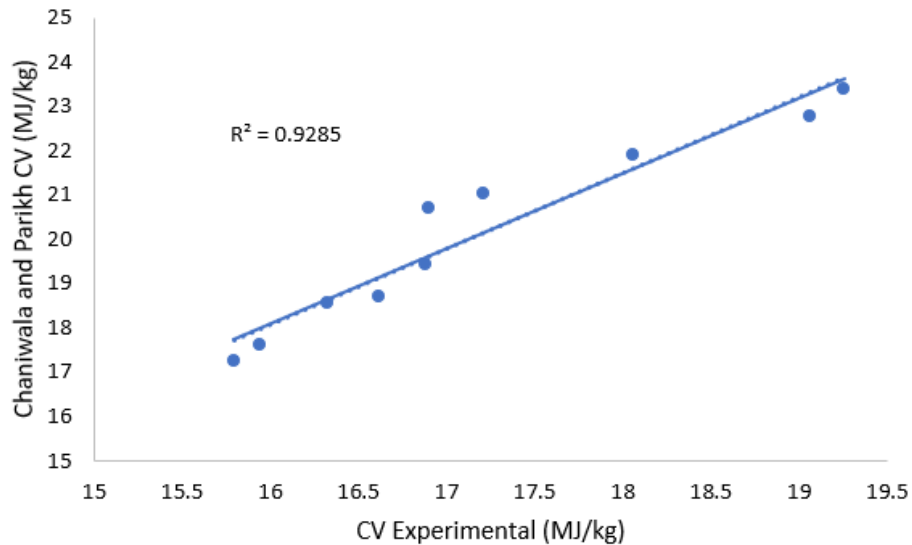
S/N	Wood specie	Density (kg/m <sup>3</sup> )	Calorific Value (MJ/kg)	Energy Content (MJ)
1.	<i>Acacia sp</i> (Acacia)	520	19.255	10015.2
2.	<i>Azelia africana</i> (Apa)	790	19.066	15065.3
3.	<i>Celtis sp</i> (Ohian)	650	17.208	11186.5
4.	<i>Brachystegia eurycoma</i> (Okwen)	730	16.324	11913.6
5.	<i>Bombax bounopozense</i> (Bombax)	370	15.792	5842.3
6.	<i>Blighia sapida</i> (Ukpe)	580	18.056	10474.8
7.	<i>Piptadeniastrum africanum</i> (Ekhimi)	480	16.901	8112
8.	<i>Cleistopholis partens</i> (Otu)	410	16.621	6814.2
9.	<i>Triplocyton scleroxylon</i> (Obeche)	320	15.944	5100.8
10.	<i>Albizia sp</i> (Albizia)	520	16.883	8777.6
	<b>Mean</b>		<b>17.205</b>	<b>9330.23</b>
	<b>Standard Deviation</b>		<b>±1.218</b>	<b>±3036.14</b>

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As shown in Table 3, the calorific value ranged from 15.792 – 19.255 MJ/kg. This is in close agreement with the findings of Huhtinen [27] who reported 18.5 – 21 MJ/kg and Akhator et al. [14] who reported 19.45 – 20.15MJ/kg. Consideration of the obtained standard deviation of ±1.218 indicates less variation in the calorific values of wood species which justifies the use of wood wastes from a mix of different wood species as commonly found in sawmills.

Fig. 1-3 show the plots obtained on comparing the experimentally obtained calorific values and the correlation-based result obtained on substituting the appropriate ultimate and/or proximate analyses parameters into the chosen correlations (equations 11-13). Fig. 1 is a

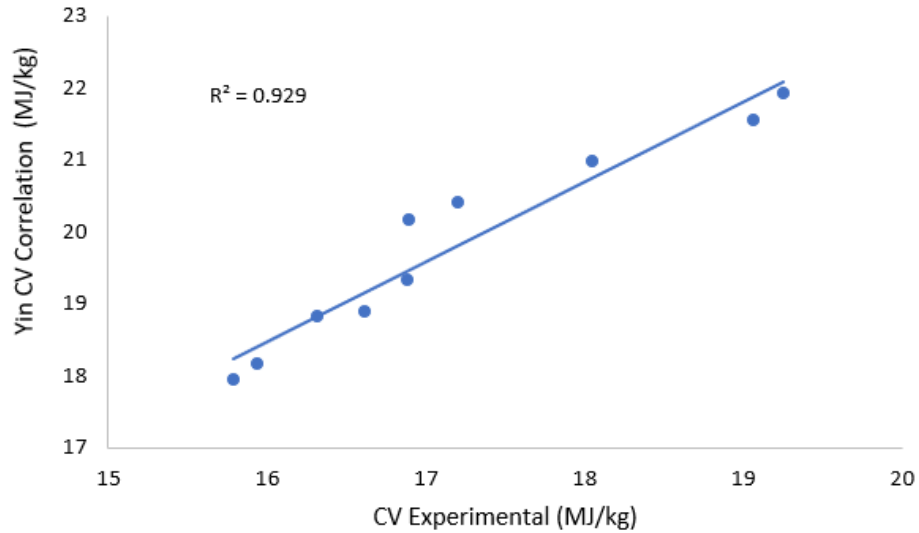
250 plot of the experimental CV against the theoretical CV obtained using the Channiwala and  
251 Parikh Correlation (equation 11). As shown in the figure, a root mean square (rms) value of  
252 0.9285 was obtained which clearly indicates a very close correlation between the  
253 experimentally obtained result and the theoretical result. For Fig. 2 which shows the  
254 relationship between the Yin correlation and the experimental result, a close relationship is  
255 also established represented by the rms of 0.929. A consideration of this obtained high rms  
256 value reveals the influence of the carbon and hydrogen contents in the energy  
257 characteristics of the wood waste as these are the only two parameters considered in the  
258 Yin correlation (equation 12). A rms of 0.8666 was obtained as shown in Fig. 3 using the CV  
259 correlation given by Garcia *et al.* (equation 13). This correlation which is a hybrid of ultimate  
260 and proximate analyses parameters gives a relatively low rms value compared to the other  
261 two former cases. This could be as a result of the inclusion of the moisture content  
262 parameter in the equation which is expected to be minimal for enhanced energy application.  
263 However, the range of high rms values obtained in the three correlation cases are indicative  
264 of a close relationship between the experimental and theoretical CV and thus, validates the  
265 obtained experimental CV results.  
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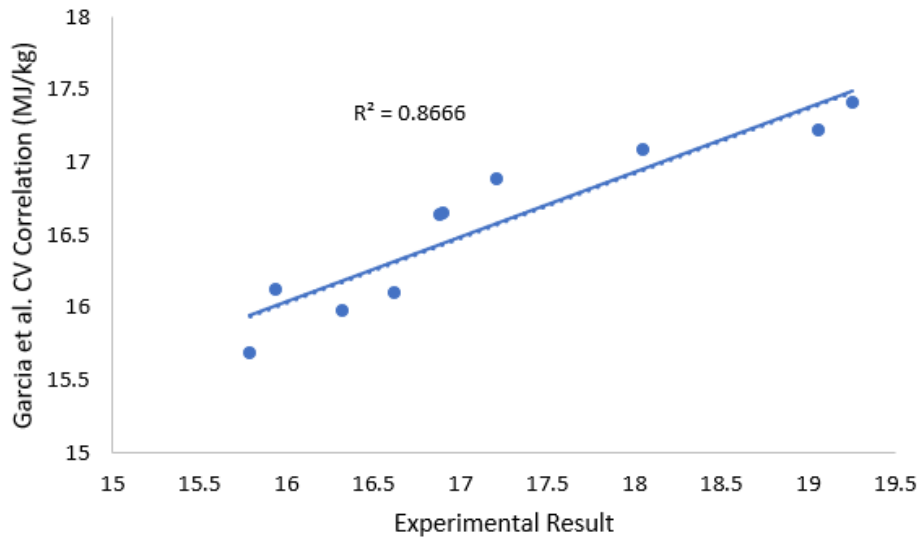
**Fig. 1. Plot of experimental CV against Channiwala and Parikh CV correlation**





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270 **Fig. 2. Plot of experimental CV against Yin CV correlation**



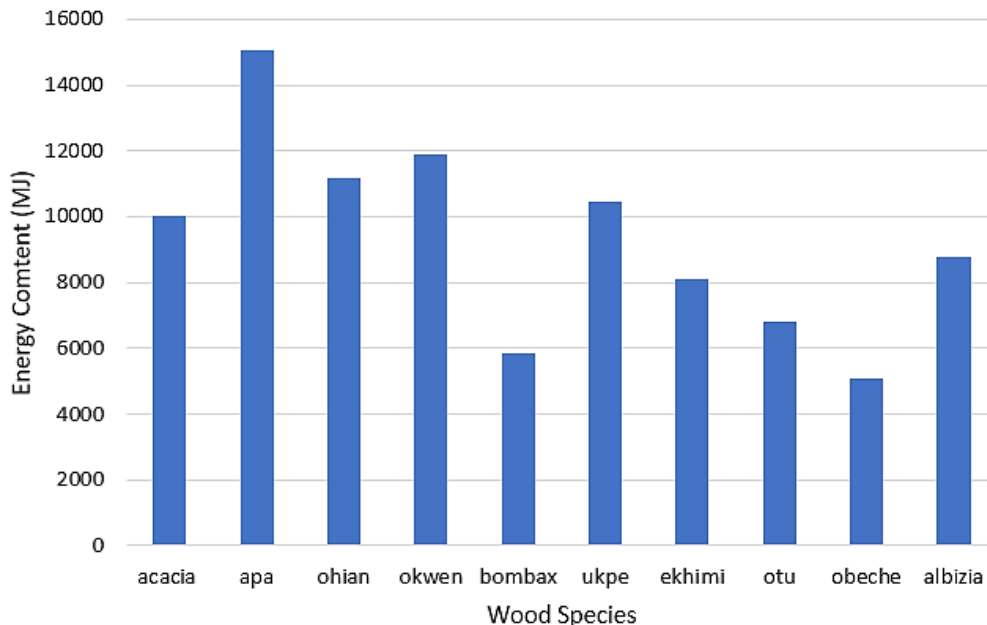
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272 **Fig. 3. Plot of experimental CV against Garcia et al. CV correlation**

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274 A consideration of the energy content as presented in Table 3 reveals a significant variance  
 275 from one wood specie to another. This variation which is directly linked to the density of the  
 276 particular wood specie for the same volume of wood waste considered shows that some  
 277 wood species are better suited for energy conversion than others. This comparison is more  
 278 properly captured in Fig. 4 which shows a comparison of the energy content obtainable from  
 279 a unit volume of waste from the ten (10) studied wood species.





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281 **Fig. 4. Energy content obtainable per volume of wood waste**

282 As shown Fig. 4, wood waste from *Azelia africana* (Apa) gave the highest energy content  
 283 value while that of *Triplocyton scleroxylon* (Obeche) gave the lowest value. A consideration  
 284 of their characteristics such as the fixed carbon, ultimate analysis as well as the calorific  
 285 values shows a similar trend that clearly indicates that *Azelia africana* (Apa) is better suited  
 286 for energy generation than the other species considered. In order to ensure optimum  
 287 exploitation of wood in energy production, such woods with higher energy potential (in this  
 288 case, *Azelia africana* (Apa)) should therefore be specially cultivated and applied either  
 289 singly or mixed with other high energy potential wood species (in this case, *Celtis sp* (Ohian)  
 290 and *Brachystegia eurycoma* (Okwen).

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#### 292 **4. CONCLUSION**

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294 The energy potential of wood waste (saw dust) from 10 selected tropical wood species have  
 295 been investigated using proximate analysis, ultimate analysis as well as energy content  
 296 study. The results obtained have shown desirable thermal conversion characteristics of low  
 297 ash content, very high volatile matter, low moisture content, relatively high carbon, hydrogen  
 298 and oxygen contents as well as low nitrogen and sulphur contents. The calorific value of  
 299 these species have been obtained experimentally and validated using three different CV  
 300 correlations with the rms value ranging between 0.8666 and 0.929. Among the 10 species  
 301 studied, *Azelia africana* (Apa) has been found to be best suited for energy generation on the  
 302 basis of obtained energy content while *Triplocyton scleroxylon* (Obeche) was found to be  
 303 least suited.

304

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306

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## COMPETING INTERESTS

Authors have declared that no competing interests exist.

## AUTHORS' CONTRIBUTIONS

This work was carried out in collaboration between all authors. Author EPA initiated the study and jointly supervised it alongside Author AIO. Author JOA managed the literature searches, carried out the field and laboratory work of the study, and wrote the first draft of the manuscript. The results and discussions were jointly done by Author JOA and Author EPA. All authors read and approved the final manuscript.

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